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HRAGM PRESSURE TRANSDUCERS TO THERMAL GRADIENTS

Leon Horn - ISA Senior Member
sicist
ional Bureau of Standards
hington, D. C. 20234

ABSTRACT

The zero signal output of pressure transducers may alter during field use in the presence of thermal gradients. The changes can be large enough to cause serious questioning of the validity of test data taken without corrections for the zero shift.

Variations of up to 100% FS (full scale) have been found using transducers that indicated less than a 6% shift in the standard steady state temperature tests.

A simple method of dynamic testing is described and experimental results are given for a number of tests.

INTRODUCTION

At the present time, pressure transducers are often considered to operate correctly within their given temperature span if their zero shift and sensitivity remain within specified limits during certain temperature tests. The environment of the test, a controlled temperature zone in a furnace, is intended to give assurances that within the limits of the temperature checked, the transducer will continue to furnish valid data.[1]

Changes in the ambient temperature can affect the output of a pressure gage by causing the zero value to shift, by altering the sensitivity or by changing the damping and thus the dynamic response.[2]

A temperature-compensating electrical network is often added in order to cancel the temperature effects known to occur in the active elements. In the case of strain gage transducers, this takes the form of small resistors added to one arm of a bridge. Dummy gages are another means of compensation that may be installed.[3,4] Although complete compensation seems impossible, the typical temperature-compensated pressure-transducer zero shift falls between 0.01% and 0.02% FS/°F (full scale per degree Fahrenheit).[5] For uniform-temperature conditions, conditions similar to those found in a controlled furnace, the test results are valid. If the conditions of a test are such that one surface of the gage will be exposed to a hot medium and the other end of the gage is in a cooler environment, the compensation may itself be the cause of a zero shift large enough to invalidate any tests being performed, since the temperature-compensating network might not be at the same temperature as the active elements of the device.

In order to determine the effect of thermal gradients on pressure transducers, a test device capable of establishing thermal gradients in the transducers was built. No attempt was made to match the heat flux rates of up to 2000 $cal/cm^2 \cdot s$[6] that were known to exist in the various industrial fields in which pressure gages can be used.*

If it is assumed that the most important effects of changing temperature are direct functions of the temperature and of its gradient, the method of establishing the gradient or the time scale during which it is achieved can be ignored for the present. Some evidence of the correctness of this assumption will be shown.

GRADIENT HEATER DESIGN

An electric soldering iron was altered to serve as the heat source for

*The calorie as used in this paper is measured at 20°C.

Superior numbers refer to similarly-numbered references at the end of this paper.

[redacted]

testing the pressure transducers. With the addition of an insulating shield and means of measuring and controlling the heat output, it was found to be capable of transferring from 0.8 cal/cm^2·s at 225°F to 7.6 cal/cm^2·s at 900°F.

The heat is transferred by thermal contact and it is possible to alter the heat flux by altering the region of contact between the heater and the transducer. The photograph (Figure 1, A and B) shows the heater system that was built.

The pressure transducer can be seen at (A). It is held by an insulated clamp (B) so that its surface is just immersed in the liquid Woods-metal pool (C) which is used as a heat-transfer medium. The heater (D) voltage is controlled by an autotransformer and thermocouples (E) are used to measure the temperature of the heater, and of the front and back surfaces of the gage. A recorder is used to keep multiple continuous records of the temperatures during the test. An air hose is used to direct the air for cooling the back of the gage, when desired.

The electrical output of the transducer is displayed on an oscilloscope and the results are photographed for a permanent record.

TEST PROGRAM AND RESULTS

Pressure transducers fall into two classes, passive and active. The passive systems do not generate signals or power, but require an auxiliary source; they will give meaningful values for constant pressures. The active units generate their own output, but the signals tend to be functions of time, and, in general, cannot be used for precise measurements of steady-state pressures. Because of this, the active systems would require a slightly different technique than the one we have used for the passive type pressure transducers.

The designed test is based on a temperature gradient being developed within the pressure transducer that is similar to the gradient one would expect under field conditions. In addition the test allows the measurement of the time temperature constant of the transducer (i.e., the length of time in which a particular design will absorb heat to establish a gradient before it starts to lose heat through its external connections). With this information, one can estimate the time that would be required to establish certain gradients for increased heat flux rates.

If the performance of a transducer is unsatisfactory under the test being given, one can assume that it will not be satisfactory in the field, where conditions are more severe.

In a typical test series one alters the temperature of the heat source in steps, running one test at each step until the specified limiting operating temperatures of the transducer are reached. The gradient of each run is noted, as well as the zero shift with time. The gradients can be increased by cooling the back of the transducer while heating the front surface, and another series can be taken.

The tests to date have been made at a maximum front surface temperature of 600°F and approximately 3 cal/cm^2·s output. The conditions for the tests reported in this paper are given in Table 1.

One of the most immediate findings of the program was the fact that the response of a transducer to a gradient could not be determined from its behavior at the temperatures listed with its specifications. For example, Figure 2 shows the results of a standard series of temperature tests to determine the zero shift in the calibration of one particular temperature-compensated pressure transducer. This instrument was listed as having an allowable zero shift of 0.02% FS/°F from -45 to +600°F; it does remain within the indicated limit for uniform steady-state temperatures. Figure 3 indicates the zero shift of the same transducer as a function of time and temperature, when subjected to thermal gradients.

The section within the lower arrow bracket represents the total zero shift for 600°F based on uniform steady-state temperature characteristics. The tests indicated zero shifts of over 40% as a result of thermal gradients.

The difference between Curves 2 and 4 is the result of increasing the initial temperature and the flux rate of the heater. The transducers were allowed to approach the temperature of the heater as rapidly as their design would permit. Curves 1, 3, and 5, however, differ in the fact that cooling air was blown across the back surface of the gage, thus causing a larger gradient to be established.

A comparison between air-cooled and normal gage installation at one input, Curves 1 and 2, and those at a higher input rate and temperature, Curves 4 and 5, indicated that: (a) the zero shift for a gradient is far more than that indicated by the uniform steady-state temperature tests; (b) cooling the back increases the eventual zero shift, although for the same input it requires a longer time for the maximum to be reached.

The rate of zero shift is related to the heat flux input and the amount of zero shift is related to the gradient established.

A study of the results of a number of tests with different transducers indicated that the time to produce the maximum gradient for a normally installed pressure transducer was a constant of the design and material and was not altered by the heat flux rate for the temperature range studied and the materials encountered.

Figure 4 is an enlargement of the initial response of the particular smooth diaphragm pressure transducer enclosed in the dotted region in Figure 3. The trace is shown as dotted for the first second, since the resolution of the output is not sufficient to determine the precise value of the zero level within this period of time. The negative shift followed by a recovery was apparent in every run, although the time to reach a minimum was not certain. The effect was similar to what is known as "oil-canning"[7] and was followed by a relatively rapid recovery. For a period of almost five seconds no valid data were obtained. The heat flux input seemed to alter the response in a repeatable manner; Curves 4 and 5 and 2 and 3 are the results of similar heat flux input.

Figure 5 shows the results of maintaining a heat source on the active surface of the transducer while a stream of cooling air was maintained across the back of the same transducer. At the end of ten minutes the transducer was approaching a steady-state condition with a zero shift of almost 47% of full scale. At the end of 30 minutes the zero shift had stabilized at 48% of full scale and appeared to have reached a condition of equilibrium.

Figure 6 is the typical output of one transducer; but in addition to the zero shift, the temperature values of both ends of the transducer are shown. For the particular unit tested, the back surface showed a change in its rate of temperature increase at about 51 seconds. This time was the same as long as one did not alter the general configuration of the test equipment. Changes in the rate of heat flux or the temperature of the heater did not change the time for this event within the range available (0.8 cal/cm^2 to 8 cal/cm^2). Within the accuracy of measurement, all that increasing the energy input did was increase the slope of the zero shift curve and increase the gradient maximum. On this graph an arrow mark indicates the time of the zero shift maximum.

The total zero shift can be considered to be composed of two parts; one, the normal shift due to the temperature of the face of the transducer assuming uniform steady-state temperatures, and the other (almost five times as large in this unit) due to the gradient involved. The sum of these maximized at about 55 seconds. The drop recorded in the zero shift afterwards would be expected, since the gradient decreases. The total zero shift must approach that found in the uniform steady-state furnace tests as the conditions become similar.

Attempts to relate test differences as due to transducer type (i.e., strain gage, differential transformer, etc.) rather than the specific design practices of particular models have been unsuccessful. We cannot, on the basis of the work performed to date, classify the types of pressure transducers as more likely or less likely to be sensitive to temperature gradients.

Figure 7 represents the data obtained from tests of three different transducers. A and B are unbonded strain gage pressure transducers by two different manufacturers. Both checked out as anticipated based on manufacturers' data for the uniform temperature test furnace, but B continued to hold well within the same limits when exposed to thermal gradients, while A responded with a large zero shift. Curve C represents the response of a differential transformer pressure transducer.

Figure 8 illustrates some of the wide variations found in the reactions of flat diaphragm pressure transducers to thermal gradients. The unit shown on Curve B indicated normal operation in the standard furnace temperature tests both before and after a thermal gradient test was applied, but it became inoperative during a gradient test in less than 20 seconds. When exposed to a thermal gradient of more than 80°F, there was more than a 100% FS zero shift.

The lower dotted curve is another pressure range of the same series from the same manufacturer with still another kind of response to a gradient. This gage did recover and after 40 seconds was within the zero shift limits for successful uniform temperature compensation.

CONCLUSIONS

1. Flush-mounted pressure gages may check as fully temperature-compensated during standard temperature tests and still show zero shifts of up to 100% FS for thermal gradients within the operating temperature range of the transducer.

2. The reaction to thermal gradients for presumably similar pressure gages made by different manufacturers is so diverse that it masks differences that may exist due to types.

3. Each transducer tested had a "time to maximum" zero shift. This "time" was a constant for a particular transducer design and material. It was not altered by changing the flux rate.

4. Although the rate of energy input and thermal flux density influence the magnitude and the time it takes to reach a given gradient value, it is the temperature gradient that is responsible for the zero shift of the instrument.

5. For a steady-state gradient there is a fixed zero shift.

6. Cooling the back surface of the transducer increases the thermal gradient and thus the zero shift.

7. "Oil canning," when it occurs, causes a self-reversing zero shift during the first few seconds after the application of a change in the surface temperature.

In summary, the results of the tests performed demonstrate that the correct operation of a pressure gage in a test furnace at a uniform constant temperature does not assure correct operation under gradient conditions. The errors involved can be very large and should be considered when choosing a pressure transducer for field use.

REFERENCES

(1) Guide for Specifications and Tests for Strain Gage Pressure Transducers for Aero Space Testing, ISA RP 37.3, April, 1964, pp. 8-11.

(2) Considine and Ross, Handbook on Applied Instrumentation, McGraw-Hill, New York, 1964, pp. 1-17.

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(4) Beckwith and Buck, Mechanical Measurements, Addison Wesley, Reading, Mass., 1961, p. 125.

(5) ISA Transducer Compendium, Plenum Press, New York, 1963.

(6) Jones, H. B., Knauer, R. C., Layton, J. P., and Thomas, J. P., Transient Pressure Measurements in Liquid Propellant Rocket Thrust Chambers, ISA Transactions, Vol. 4, No. 2, April, 1965.

(7) Patterson, J. L., A Miniature Electrical Pressure Gage Utilizing a Stretched Flat Diaphragm, NACA Technical Note 2659, April, 1962

TABLE I

Figure	Curve Number	Transducer	Max. Temp. on Face °F	Conditions of Test Back Surface
3	1	A-3	300	cool air on back
	2	A-3	375	exposed, not cooled
	3	A-3	380	cool air on back
	4	A-3	580	exposed, not cooled
	5	A-3	545	cool air on back
4	Same as Figure 3			
5	Same as Curve 5, Figure 3			
6	1	A-3	250	exposed, not cooled
7	A	B-11	300	exposed, not cooled
	B	B-12	212	exposed, not cooled
	C	C-1	300	exposed, not cooled
8	A	B-13	200	exposed, not cooled
	B	B-8	230	exposed, not cooled

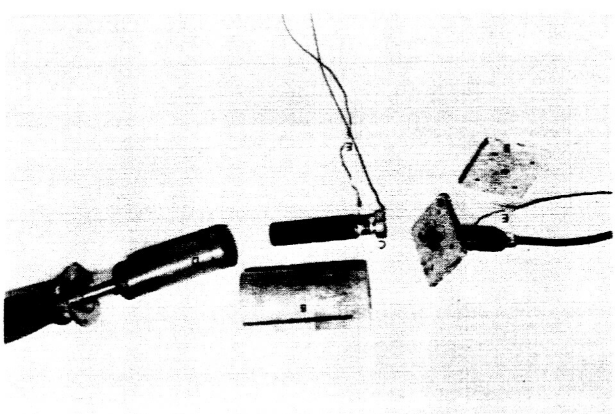

Figure 1A Gradient Heater

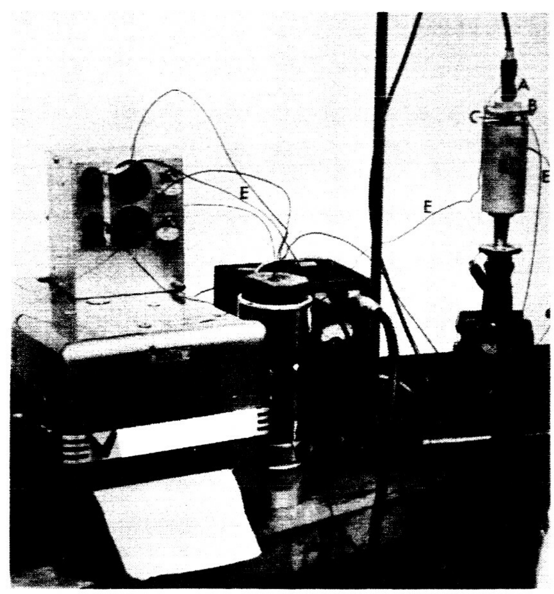

Figure 1B **Gradient Heater**
System in Operation

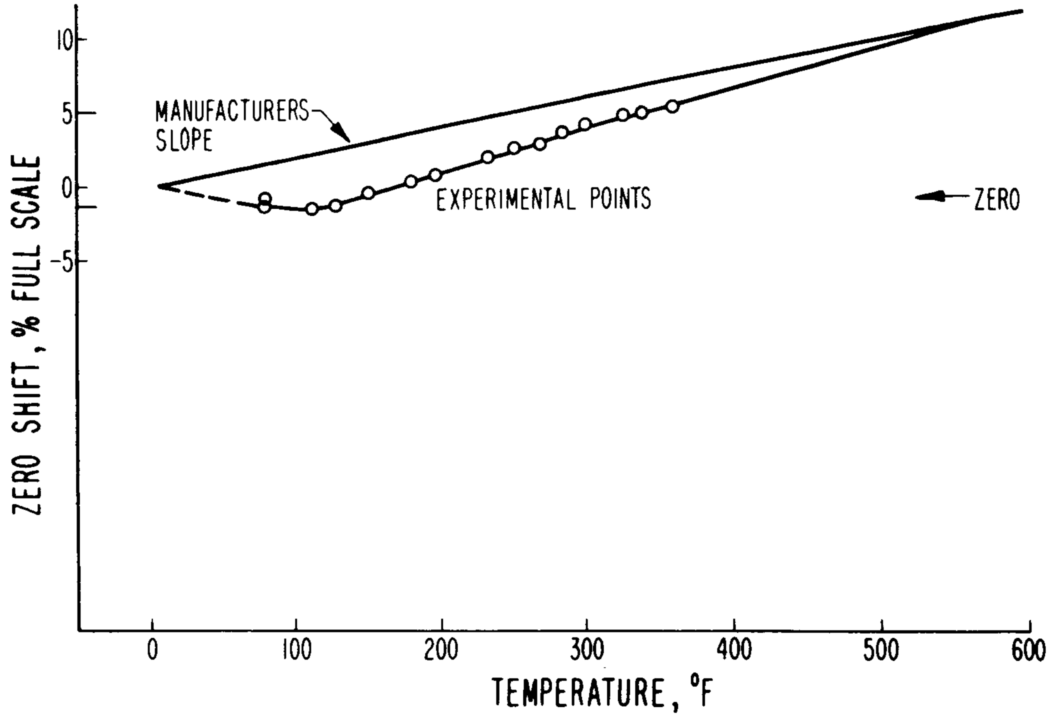

FIGURE 2 PRESSURE GAGE ZERO CALIBRATION (STATIC)

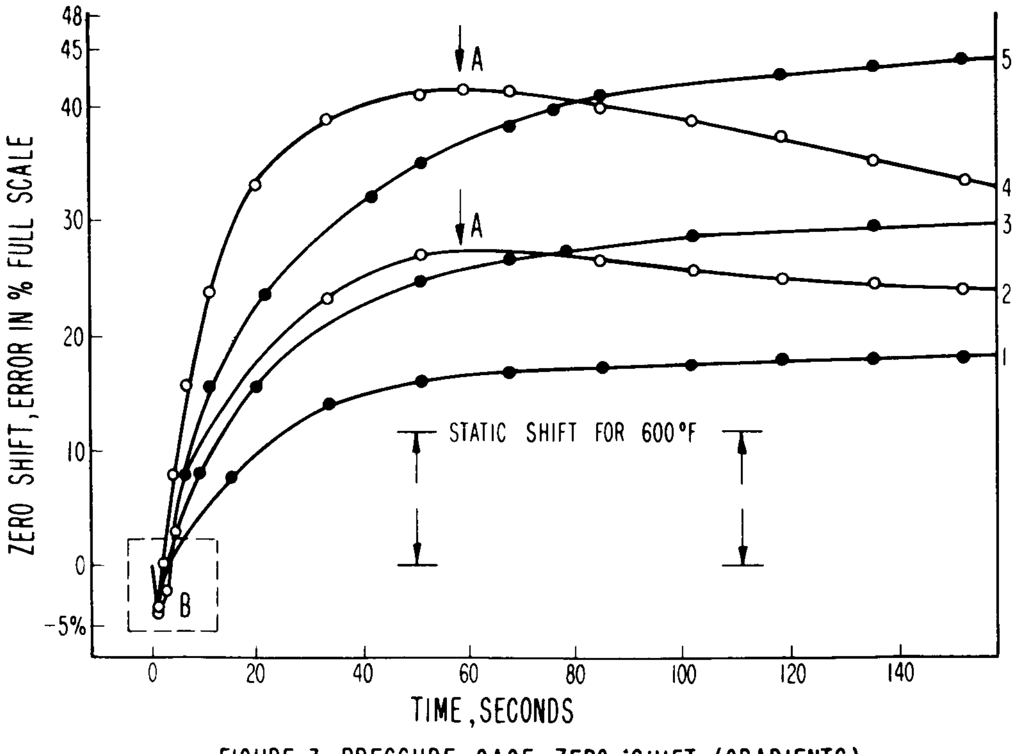

FIGURE 3 PRESSURE GAGE ZERO SHIFT (GRADIENTS)

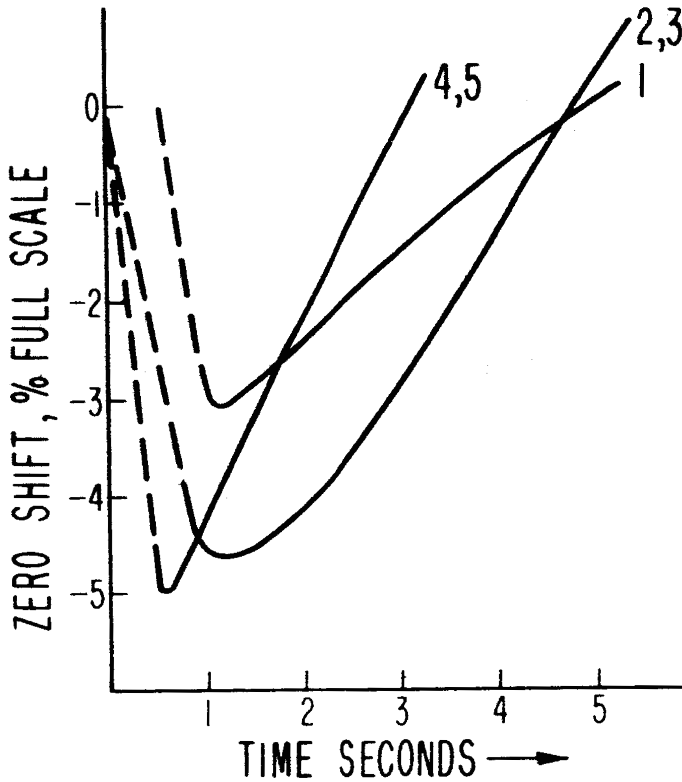

FIGURE 4 ENLARGEMENT OF AREA B

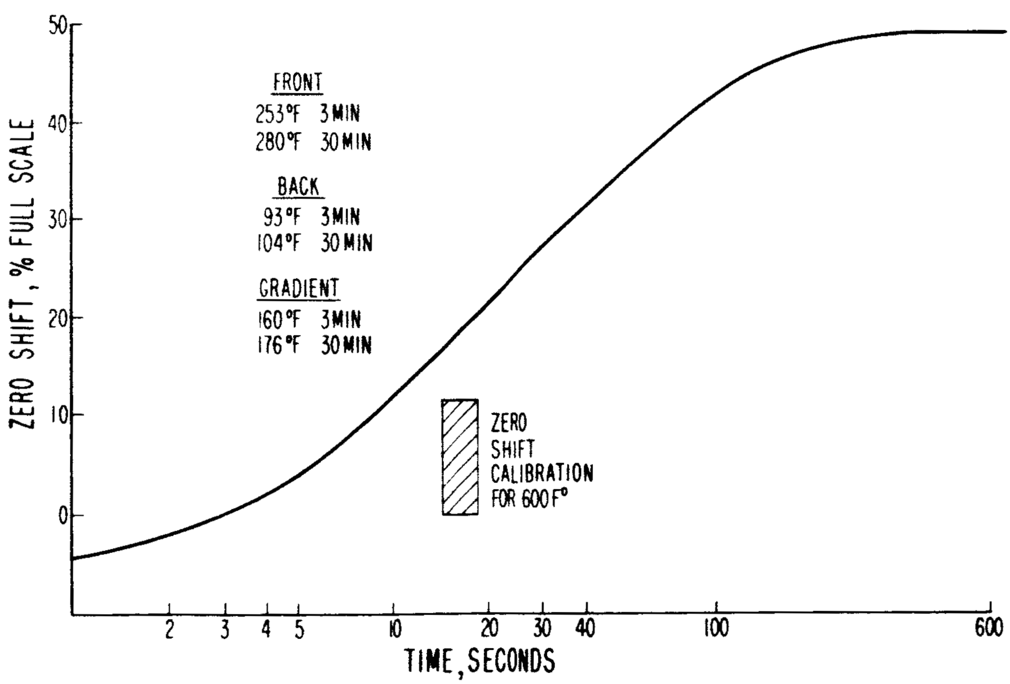

FIGURE 5 LONG TERM GRADIENTS

4 8
9 ... 5

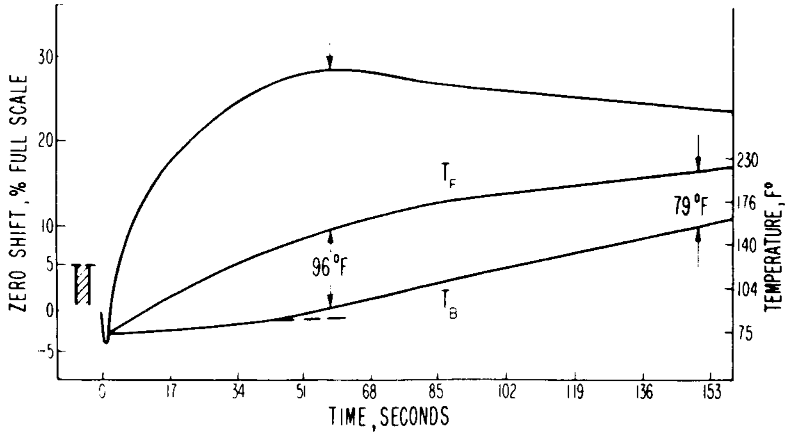

FIGURE 6 TEMPERATURE GRADIENT EFFECT ON ZERO SHIFT

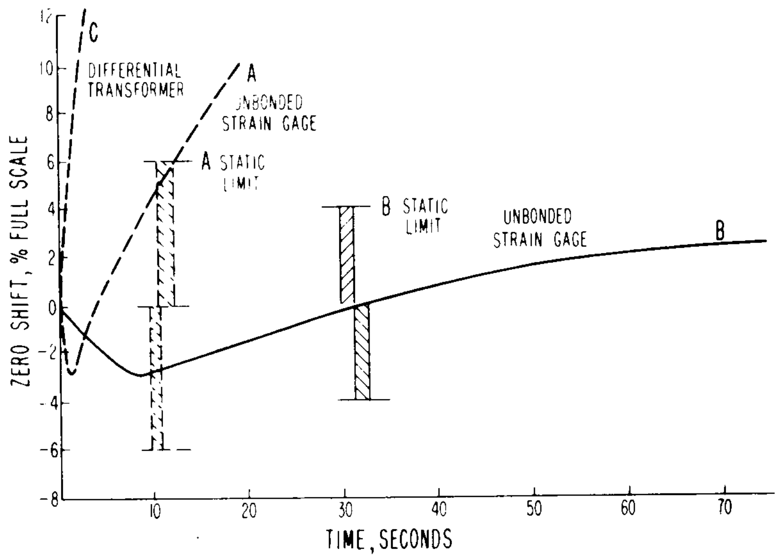

FIGURE 7 THERMAL RESPONSE

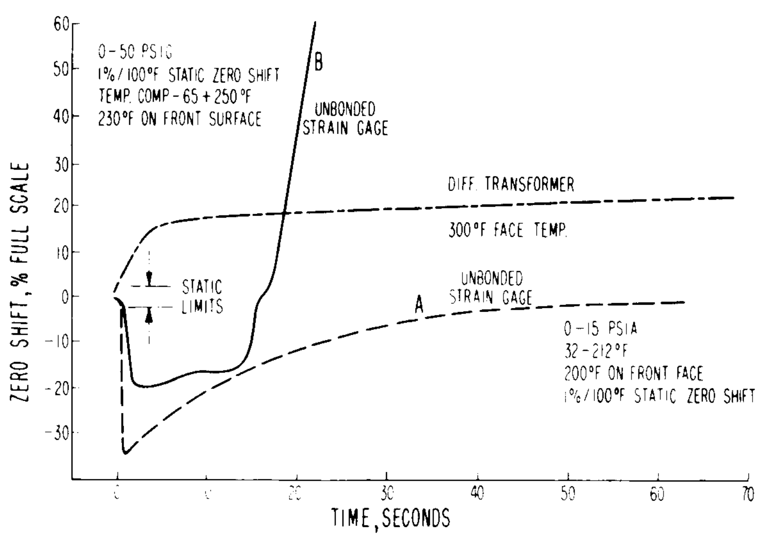

FIGURE 8 THERMAL REPSONSE

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